Refractivity from Clutter and Refractivity Data Fusion

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LONG-TERM GOALS

The long-term goals of this research are to provide accurate mesoscale analyses and forecasts of microwave refractivity and to quantify the impacts of refractive effects upon Naval communications and weapons systems. Such refractive effects are of particular importance to strike warfare and ship self-defense.

OBJECTIVES

The objectives of this research are to enhance numerical weather prediction approaches to analyzing (nowcasting) and forecasting microwave refractivity and the concomitant refractive effects upon Naval combat systems and communications.

APPROACH

The approach used is multifaceted and multi-disciplined. The Navy's Coupled Ocean/Atmosphere Mesoscale Prediction System (COAMPS™)[1] run with high horizontal and vertical resolution, is used to analyze and forecast refractivity structure and to provide background fields for inversion techniques such as used in extracting Refractivity-From-Clutter (RFC). To refine and validate this approach, data from special electromagnetic (EM) propagation field experiments are used. During April-May 2000 at Wallops Island, VA, extensive EM propagation loss measurements along radial paths away from the coast were conducted in conjunction with extensive near-surface meteorological measurements (Stapleton et al. 2001) and this data set is being used in conjunction with our COAMPS forecasts. We have received Wallops-2000 data from several sources that participated in that field experiment (Dr. Rob Marshall, NSWCDD; Dr. Ken Davidson, NPS; Dr. Ross Rottier, Johns Hopkins APL), we have supplied COAMPS™ fields to SPAWARSYSCEN, San Diego (Mr. Ted Rogers), and we will continue to foster collaboration amongst these groups. We are also analyzing COAMPS performance in forecasting refractivity in synoptic settings other than that of Wallops-2000.

WORK COMPLETED

1. A journal article on the impact of an island wake upon atmospheric refractivity and radar propagation was published (Burk et al., J. Appl. Meteor, vol. 42, 349-367, Mar. 2003).
2. A 3-day period during Wallops-2000 was selected for initial testing of COAMPS ability to forecast refractive structure during synoptically active conditions in a complex coastal environment.

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[1] COAMPS™ is a trademark of the Naval Research Laboratory.

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14. ABSTRACT

The long-term goals of this research are to provide accurate mesoscale analyses and forecasts of microwave refractivity and to quantify the impacts of refractive effects upon Naval communications and weapons systems. Such refractive effects are of particular importance to strike warfare and ship self-defense.

15. SUBJECT TERMS

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3. Results from this preliminary study using COAMPS in conjunction with Wallops-2000 data were published (and presented orally) at the 5th AMS Coastal Conference (Seattle, Aug. 2003) and at the Battlespace Atmospheric and Cloud Impacts on Military Operations (BACIMO) Symposium (Monterey, Sep. 2003).

4. The seasonal variability of refractivity conditions along the U.S. West Coast were compiled based on hourly data from COAMPS reanalyzes. Monthly averaged ducting properties were computed for a select month during each season and results were presented in a poster and a paper at BACIMO 2003.

RESULTS

Refractive effects tend to be most prominent in regions having a subsidence-dominated marine boundary layer (MABL); these conditions tend to produce substantial horizontal homogeneity along with pronounced gradients in temperature and moisture at MABL top. Modeling studies of refractive effects are limited in number and have focused almost exclusively on such high-pressure, inversion-capped MABL conditions. As our first case study from the month-long Wallops-2000 experiment, we selected a very synoptically challenging period (10-12 April 2000) in which a stationary front or cold front was consistently in the vicinity of Wallops Island. A triply nested COAMPS grid structure (3 km spacing on the innermost mesh) centered on Wallops Island is utilized, along with very high vertical resolution (9 levels in the lowest 100 m).

First we have examined the impact of sea surface temperature (SST) upon the field of evaporation duct height (EDH). The primary determinant of EDH is the temperature and, most particularly, the moisture profile within the atmospheric surface layer, which in COAMPS are determined from stability-dependent similarity expressions. The SST varies by ~15^0C from the warm Gulf Stream (SE quadrant of 3 km grid) to the coast at Wallops Island, and our COAMPS forecasts show substantial impact of this SST gradient on the surface fluxes and, in turn, the EDH field. The heterogeneity in EM ducting conditions generated by this forcing was a primary object of study in Wallops-2000 and our COAMPS modeling adds mesoscale spatial and temporal continuity lacking in the local field data set.

We now briefly discuss the nature of trapping layers other those associated with EDH. The synoptic influences exerted by the presence of a frontal boundary throughout this period are very prominent. In the warm sector the marine BL tends to be quite moist and, when coupled with the tendency for a capping inversion, yields frequent elevated ducting that may occasionally be surface based. Although the moisture content of the cold air behind a front is substantially reduced from that in the warm sector, the sharp frontal inversion can produce an elevated trapping layer, particularly near the leading edge of a cold front. Figure 1 (viewed from the west looking east) shows trapping layer ‘clouds’ associated with a frontal surface that is propagating to the SE, having crossed the Virginia coast and moved out over the Atlantic Ocean. The ‘clouds’ are an isosurface that outlines the trapping volume within which the gradient of modified refractivity, dM/dz, is negative. The vertical cross section that angles towards the SE displays potential temperature, shaded and contoured. The sharp potential temperature gradient associated with the frontal boundary is evident. At the surface, the figure shows streamlines and color shaded EDH over water (land is blue and has no EDH). The front is seen to substantially impact the EDH field as well.

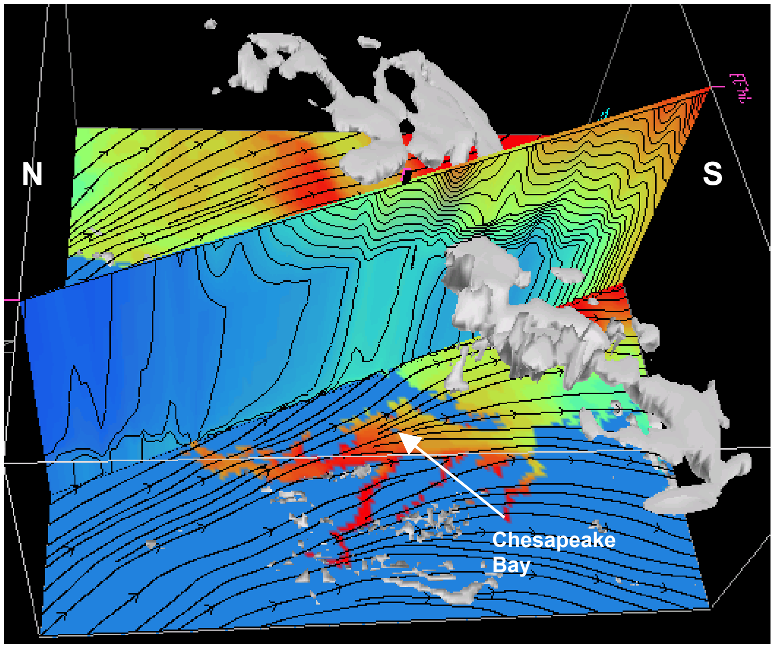

Figure 1. COAMPS forecast valid 1800 UTC 12 Apr 2000 as cold front pushes SE over the Atlantic. Displayed are white trapping layer isosurface ('trapping clouds'), vertical cross section of potential temperature (from the surface to 1 km), and horizontal plot of EDH (shaded) and streamlines.

While the cold front pushes vigorously southward on 12 April and has a strong vertical gradient producing considerable ducting, on the preceding day it is a stationary front and there is much less trapping. The vertical gradients across the stationary front (not shown) are not as pronounced as those associated with the propagating cold front. Although we have not quantitatively analyzed the COAMPS frontogenic terms, the contribution of the deformation and tilting terms to frontogenesis is very likely greater in the advancing cold front than the stationary front.

Other noteworthy aspects of the refractivity structure near the leading edge of this cold front are also being studied. Overlying the trapping layer at the leading edge of the front (Figure 1) is a *subrefractive* layer in which dM/dz > 157 M-units/km. This subrefractive layer persistently overlies the trapping layer as the cold front pushes southward.
The cross section in Fig. 2 shows contours of modified refractivity, M, and shaded dM/dz. Regions of small or negative dM/dz are blue in the vertical cross section, while strong positive values of dM/dz are red. Thus, Fig. 2 clearly shows that a layer of strongly positive dM/dz caps the trapping layer along the frontal boundary.

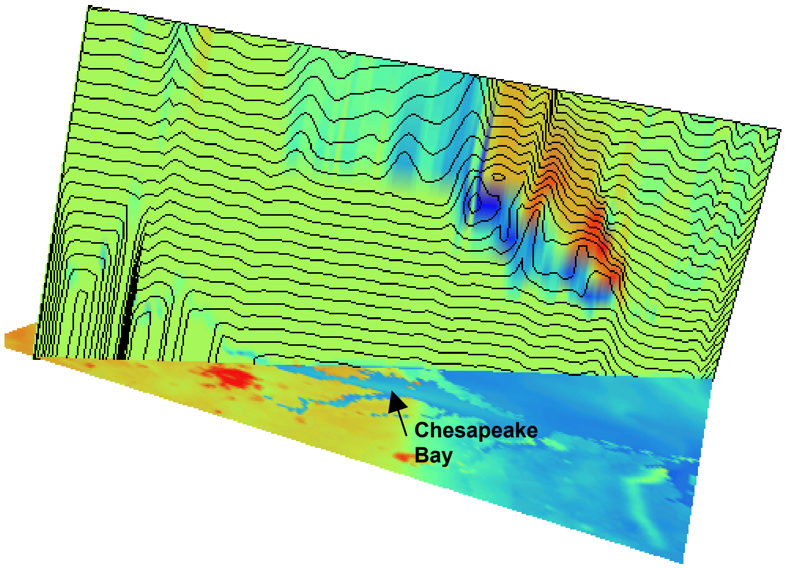

Figure 2. Modified refractivity, M, contoured and dM/dz shaded in vertical plane at same time as fig.1. Subrefraction (red) overlying trapping (blue) is evident.

To better understand the thermodynamic structure that produces this distinct refractivity layering, in Fig. 3 we display contours of potential temperature and mixing ratio (shaded). Here larger values of water vapor mixing ratio are in red, while small values are blue.

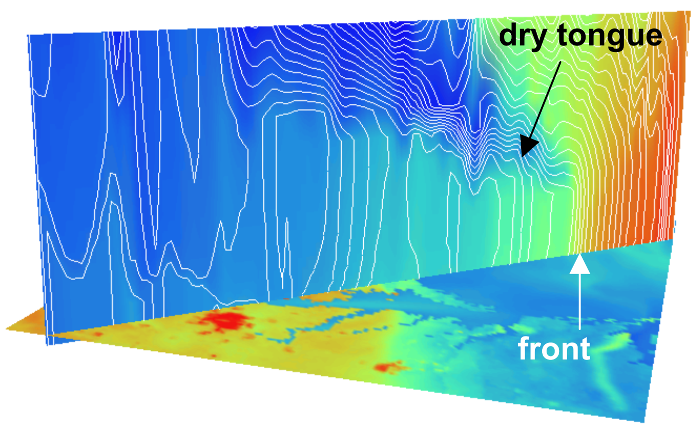

Figure 3. Potential temperature (white contours) and water vapor mixing ratio (shaded in vertical plane; scale in g/kg) at same time as figs.2-3.

The moist, well-mixed BL ahead of (i.e., to the south) the cold front is evident by the vertical potential temperature contours and the red shading. Interestingly, associated with the frontal boundary we see the strong stability as well as a tongue of dry air in the inversion layer. This dry tongue of air has moist air above it from the prefrontal BL. Differential advection of moisture associated with the advancing cold front creates this thermodynamic structure. Trajectory analysis (not shown) indicates that the dry tongue is formed from air within the cold sector that descends and advances toward the SW, while the moist air above the dry tongue is from within the warm sector and is moving toward the ESE. Near the surface, BL processes weaken the horizontal moisture gradient, while air in the dry tongue is from outside the BL. The presence of the dry tongue at the front's leading edge is responsible for both the trapping layer and the subrefractive layer, as first there is a sharp moisture decrease and then a moisture increase in passing vertically upward through the dry tongue.

The 3D visualizations in Figs. 1-3 are useful for qualitatively depicting the relationship between frontal gradients and trapping layers, etc. However, for operational purposes it is necessary to have a quick, easily understood method of *quantitatively* displaying the position and strength of ducting layers at any given forecast time. Thus, we have created plots that display the COAMPS forecast values of *duct base height, duct thickness, and duct strength.* These products have been tested, transitioned, and implemented for operational use at Fleet Numerical Meteorology and Oceanography Center. Figure 4, which displays the COAMPS forecast duct base height during the cold frontal passage described above, provides one example of these products.

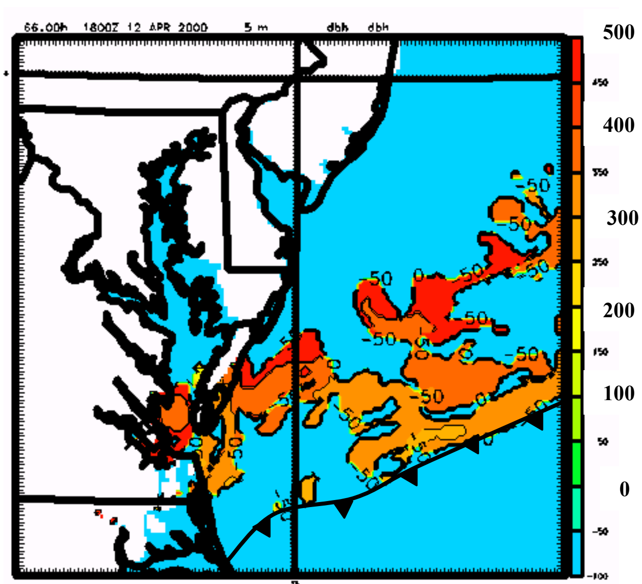

Figure. 4. COAMPS forecast duct base height (m) at 1800 UTC 12 Apr 2000. A band of elevated ducting associated with a cold front is quantified here. Blue indicates no ducting.

IMPACT/APPLICATIONS

Strike warfare, ship self-defense, and basic Naval communications and surveillance can all be strongly impacted by EM refractive effects.
This project addresses both high-resolution numerical weather prediction of refractivity and the implications of the predicted refractive state for EM propagation/ Naval operations. The new capability to map radar-ducting parameters over a mesoscale domain from COAMPS analyses and/or forecasts has been supplied to FNMOC. Validation and refinement of forecast refractivity structure over a wide-range of synoptic conditions will provide improved background ('first guess') fields for the RFC inversion technique. Improvements in knowledge of refractivity conditions from RFC are expected to permit optimization of radar performance.

TRANSITIONS

Software within COAMPS that permits the computation and graphical display of EM ducting characteristics over a mesoscale domain has been transitioned to FNMOC and support is being continued.

RELATED PROJECTS

The 6.2 Refractivity-from-Clutter program (PI: Ted Rogers) at SPAWARSYSCEN, San Diego is closely linked to the work in this project. Model development improvements to COAMPS (particularly those relating to boundary layer and moist physics), such as 6.2 Advanced Moist Physics Modeling (6766; NRL base funded), 6.2 Improved COAMPS Land Boundary Layers (6672; NRL base funded), and 6.2 Advanced Surface Flux Parameterization (8068;ONR funded) are important to this project.

PUBLICATIONS

Burk, S.D., T. Haack, L.T. Rogers, and L.J. Wagner, 2003: Island wake dynamics and wake influence on the evaporation duct and radar propagation. *J. Appl. Meteor.*, 42, 349-367.

Burk, S.D. and T. Haack, 2003: Refractivity in the coastal atmospheric boundary layer. *Fifth Conf. Coastal Atmos. & Oceanic Pred. & Proc.*, Seattle, WA, 147-150.

Burk, S.D. and T. Haack, 2003: Refractivity in the coastal atmospheric boundary layer. *BACIMO*, Monterey, CA, in press.

Haack, T. and S.D. Burk, 2003: Seasonal variability of refractivity conditions along the U.S. West Coast: A comparison of monthly averaged ducting properties. *BACIMO*, Monterey, CA, in press.